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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 June 2004 (03.06.2004)

PCT

(10) International Publication Number
WO 2004/046777 A1

(51) International Patent Classification⁷: G02B 6/16, 6/18

(21) International Application Number: PCT/AU2003/001564

(22) International Filing Date: 21 November 2003 (21.11.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2002952812 21 November 2002 (21.11.2002) AU
2003901882 16 April 2003 (16.04.2003) AU

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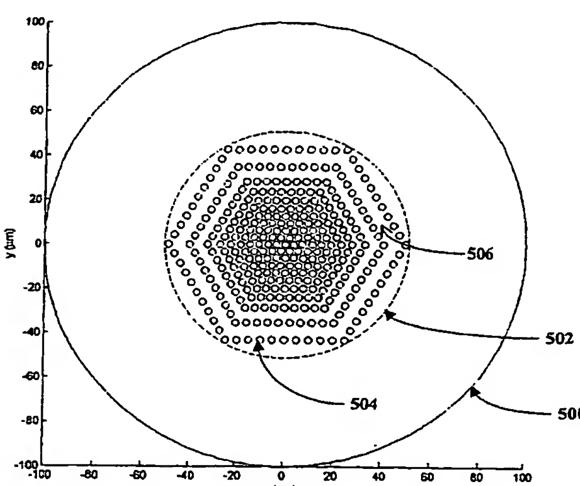
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MICROSTRUCTURED POLYMER SIGNAL GUIDING ELEMENT



(57) Abstract: A process of fabricating a polymer based microstructured signal guiding element (500), such as a polymer microstructured optical fiber, having at least one core-region (502) is disclosed. The process includes the steps of forming a preform body from a polymer based body material (506); forming a plurality of channels (504) in the preform body filled with a filler material having a different refractive index than the polymer based body material; and forming the signal guiding element from the preform body by a formation process, wherein the filler material is chosen such that processing characteristics of the body material and the filler material relevant to the formation process of the signal guiding element are substantially similar, whereby the formation process is applied to the preform body incorporating the filled channels. Preferably, the channels (504) are disposed in the preform body such that the formed signal guiding element (500) exhibits a substantially graded refractive index profile in the core region (502).

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Microstructured Polymer Signal Guiding Element

Field of the invention

The present invention relates to microstructured signal guiding elements that contain polymer material. The invention has particular application to graded index polymer fibres and a method for producing such fibres, although the invention can also be applied to polymer rods. For example, polymer rods may be fabricated by the method of this invention with a large cross section which can be used to transmit RF and terahertz data.

Therefore, whilst the invention is described hereinafter primarily in the context of optical fibres, it should be appreciated that the invention is not limited to this particular field of use.

Background of the invention

Multimode optical fibres can have large cores which enable low installation costs. In order to achieve high data transmission rates, these multimode fibres preferably have a graded refractive index profile, since this provides correction for modal dispersion and allows transmission of data over much greater distances and bandwidths than an optical fibre of an equivalent core size with a stepped refractive index profile.

However, the manufacture of glass optical fibres meeting those requirements, in particular the desired large core dimensions, is relatively expensive, and furthermore such glass optical fibres would become essentially stiff structures at the dimensions required. Clearly, this is not desirable for use in deployment of short-haul optical networks.

A least preferred embodiments of the present invention seek to address one or more of the above problems, or at least to provide a useful alternative.

Summary of the invention

In accordance with a first aspect of the present invention, there is provided a process of fabricating a polymer based microstructured signal guiding element having at least one core-region, the process comprising the steps of forming a preform body from a polymer based body material; forming a plurality of channels in the preform body filled with a filler material having a different refractive index than the polymer based body material; and forming the signal guiding element from the preform body by a formation process, wherein the filler material is

chosen such that processing characteristics of the body material and the filler material relevant to the formation process of the signal guiding element are substantially similar, whereby the formation process is applied to the preform body incorporating the filled channels.

Preferably, the channels are disposed in the preform body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining the at least one core-region of the signal guiding element.

The signal guiding element may be arranged, in use, to transmit data in regions of the electro-magnetic spectrum within the optical regime or outside the optical regime, for example electromagnetic signals in the RF and/or terahertz range.

In one embodiment, the channels extend substantially contiguously along the length of the signal guiding element.

Preferably, the filler material comprises one or more of a group comprising a polymer, a polymer plus dopant, an inorganic material, a metal, and a composite material.

Preferably, a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central.regions. Advantageously, the refractive index of the filler material is higher than that of the body material. Light propagation in the core-region is, in use, through the filler material. The central regions of the one or more core-regions may be in the form of central channels filled with the filler material.

The refractive index of the filler material may be lower than that of the body material.

The signal guiding element may be arranged as a single-mode or a multi-mode signal guiding element.

Preferably, the channels are disposed in the preform body such that the formed signal guiding element exhibits a desired modal dispersion and transmits data in a dispersion managed format.

The substantially similar processing characteristics of the body material and the filler material may comprise one or more of a group comprising viscosity, coefficient of thermal expansion (CTE) and surface energy.

The step of forming the preform body from the body material and/or the step of forming the plurality of filled channels in the preform body may comprise utilising casting techniques.

The step of forming the preform body from the body material may comprise providing a solid or fluid rod of the body material manufactured utilising drawing and/or extrusion techniques.

The process may be implemented utilising an extrusion system, wherein the forming of the preform body, the forming of the plurality of filled channels, and the forming of the signal guiding element steps occur substantially simultaneously during the formation process along an extrusion path of the extrusion system.

In accordance with a second aspect of the present invention, there is provided a process of fabricating a polymer based microstructured signal guiding element, the process comprising the steps of forming a main body of the signal guiding element from a polymer based material; and forming a plurality of channels in the main body; wherein the channels are disposed in the main body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining at least one core-region of the signal guiding element.

Preferably, a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

The channels may be hollow or filled with a filler material.

In accordance with a third aspect of the present invention, there is provided a polymer based microstructured signal guiding element having at least one core-region, the signal guiding element comprising a main body made from a polymer based body material; and a plurality of channels in the main body filled with a filler material having a different refractive index than the polymer based body material; wherein the filler material is chosen such that processing characteristics of the body material and the filler material relevant to a formation process of the signal guiding element are substantially similar, whereby the body material and the filler material have been subjected to said same formation process.

Preferably, the channels are disposed in the preform body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining the at least one core-region of the signal guiding element.

In one embodiment, the signal guiding element is arranged, in use, to transmit data in regions of the electro-magnetic spectrum within the optical regime or outside the optical regime.

The channels may extend substantially contiguously along the length of the signal guiding element.

The filler material may comprise one or more of a group comprising a polymer, a polymer plus dopant, an inorganic material, a metal, and a composite material.

Preferably, a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions. Advantageously, the refractive index of the filler material is higher than that of the body material. Light propagation in the core-region may be, in use, through the filler material. The central regions of the one or more core-regions may be in the form of central channels filled with the filler material.

The refractive index of the filler material may be lower than that of the body material.

The signal guiding element may be arranged as a single-mode or multi-mode signal guiding element.

Preferably, the channels are disposed in the preform body such that the formed signal guiding element exhibits a desired modal dispersion.

The substantially similar processing characteristics of the body material and the filler material may comprise one or more of a group comprising viscosity, coefficient of thermal expansion (CTE) and surface energy.

In accordance with a fourth aspect of the present invention, there is provided a polymer based microstructured signal guiding element comprising a main body made from a polymer based material; and a plurality of channels in the main body; wherein the channels are disposed in the main body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining at least one core-region of the signal guiding element.

Preferably, a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

The channels may be hollow or filled with a filler material.

Brief description of the drawings

Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings.

Figures 1A to C are schematic drawings illustrating a fabrication process embodying the present invention.

Figures 2A and B are schematic drawings of a cross section view of the core-region, and the refractive index profile in that region respectively, of an optical fibre embodying the present invention.

Figure 3 is a schematic drawing showing a cross sectional view of the core-region of an optical fibre embodying the present invention.

Figure 4 shows the graded refractive index profile in the core-region of the optical fibre of Figure 3.

Figure 5 is a schematic drawing showing a cross-sectional view of an optical fibre embodying the present invention.

Figure 6 shows the graded refractive index profile in the core-region of the optical fibre of Figure 5.

Figure 7 is a schematic drawing showing a cross-sectional view of an optical fibre embodying the present invention.

Figure 8 shows a schematic drawing of an extrusion system for manufacture of an optical fibre.

Figure 9 shows a schematic drawing of a casting system for manufacture of a preform for an optical fibre.

Detailed description of the embodiments

In one embodiment, the present invention provides a microstructured polymer fibre in which hollow channels extending along the length of the optical fibre are disposed in a manner such that the polymer optical fibre exhibits a substantially graded refractive index profile defining at least one signal propagating region or core-region of the optical fibre. The term "graded refractive index profile" is not intended to be limited to any particular refractive index profile, but rather is intended to cover more broadly a more refined refractive index profile than

a "conventional" core/cladding stepped refractive index profile, and includes what is sometimes referred to as multi-step refractive index profiles.

Preform preparation techniques such as capillaries stacking, polymerisation casting, drilling, extrusion and injection moulding can be modified to implement such an embodiment. Such an embodiment may be implemented for fabrication of e.g. an optical fibre by direct extrusion through a die, rather than from a preform.

This example embodiment of the present invention in its different implementations can provide microstructured polymer signal guiding elements comprising a plurality of hollow channels arranged such that an averaging effect results in a graded refractive index profile, as is desired for many applications as outlined in the background of the invention section.

In the following, features of a different group of embodiments of the present invention will now be described, which can address some of the limitations associated with airfilled microstructured signal guiding elements in the example embodiment described above. Those limitations include strength and durability issues, associated with cutting of such signal guiding elements, surface roughness considerations with airholes and potential collapsing of small airholes, and material contamination and condensation within airholes. However, it will be appreciated that the embodiment described above still provides a useful solution where such limitations are not critical, or outweighed by ease of manufacturer and/or cost effectiveness considerations.

Figures 1A-C illustrate the basic elements of a formation process for a microstructured polymer optical fibre embodying the present invention.

In Figure 1A, a preform body 10 is provided in the form of a polymer rod 10. As indicated in Figure 1B, a plurality of material filled channels e.g. 12 are provided in the preform body 10. The filler material of the filled channels 12 is chosen from "like material" when compared with the material of the preform body 10. The disposition, dimensions and shapes of the filled channels 12 are chosen to achieve a desired optical characteristic in the resulting optical fibre, e.g. to create a graded refractive index profile around a central axis of the optical fibre. Furthermore, a protective cladding sleeve or coating layer 13 is provided around the polymer rod 10. The material for the cladding sleeve 13 is chosen from "like material" when compared with the material of the preform body 10, and in the example embodiment is the same as the filler material in the filled channels 12.

As illustrated in Figure 1C, the preform body 10 incorporating the filled channels e.g. 12 is then subjected to a fibre formation process, in the example embodiment a conventional fibre drawing technique indicated in Figure 1C by box 14, for drawing of the optical fibre 16. Processing characteristics of the body material and the filler material relevant to the formation process of the signal guiding element are substantially similar in the "like material" approach of the embodiment. As a result, the application of the formation process to the preform body 10 incorporating the filled channels 12 preferably affects the body and filler material in substantially the same way, thus avoiding introduction of unwanted differential changes between the body and channel materials. In example embodiments, the body material and the filler material may have similar viscosity, and/or coefficient of thermal expansion (CTE) and/or surface energy.

Figure 2A and B show a schematic drawing of a cross sectional view of the core-region 100, and the graded refractive index profile 102 in that region respectively, for an optical fibre embodying the present invention.

Turning initially to Figure 2A, the core-region 100 comprises a central area 104 of a body material having a refractive index n_0, and a plurality of filled channels e.g. 106 with a filler material having refractive n_1. The filled channels e.g. 106 are arranged in concentric rings, with the number and size of the channels for each ring varying to achieve the graded refractive index profile 102 shown in Figure 2B. In the example embodiment, a typical diameter of the core-region 100 would be about 120μm, with a concentric cladding region (not shown) around the core-region 100, formed from a material having a refractive index of n_1 or lower.

Also shown in Figure 2B is the theoretical graded index profile 108, which the fibre was designed to approximate. By comparison, the curve 102 shows the average circularly symmetric index profile of the core-region of the actual fibre. As mentioned previously, the term "graded refractive index profile" is intended to include a profile such as curve 102 in Figure 2B, which may sometimes be referred to as a multi-step refractive index profile.

In the embodiments described with reference to Figures 1 and 2, the refractive index of the filler material is chosen to be lower than the refractive index of the material of the preform or main body. In the following, some typical design features of optical fibres of that type, i.e. using higher index polymer as body material when compared with the filler material, will be described:

- Light propagation in that type of fibre is through the body material.

- The filler material could be one or more materials with indices $n_1 \ldots n_x$, which are lower than the refractive index of the body material.

- A ratio of channel areas to main body area in cross-sectional ring areas around a central region of respective one or more core-regions of the fibre increases as a function of distance from the central regions.

- The average effective index of the out layers in that type of fibre will be gradually lower than in the central region, i.e. lower than that of the body material index. This results in the average effective index gradually decreasing with distance from the central region, thus creating a graded refractive index profile.

- The graded refractive index profile can be designed to manage or minimise modal dispersion.

- The core-region size can be varied to above 0.5mm in diameter depending upon design, such as variations on number of rings of channels, channel and main body ratio, the use of different channel arrangements, channel density and/or cross-sectional size and/or variations with radius, and/or other parameters.

- The transmission window for fibres of that type for currently available materials is expected to be from 510nm to 1310nm. However, it is noted that the provision of new materials may expand the transmission window in the future.

- By using higher index polymer as body material and large overall core-region size, there are typically thousands of modes supported into a fibre of that type. Confinement problems may occur for the modes, which is sometimes referred to as modes leaking. However, a proper design, using appropriate design parameters such as channel arrangement, channel size, shape of the overall structure, or increasing number of rings of channels, is expected to reduce confinement loss down to negligible values if required.

It has been recognised that the "like material" approach for body and filler materials in the fabrication of microstructured polymer optical fibres for other signal guiding elements provides a number of advantages, including a superior strength and durability of the resulting fibre, improved susceptibility to any handling or post fabrication processing of the optical fibre

such as easier cutting of the fibre across the interfaces of the like materials, and a reduction or even elimination of surface related problems at the main body/filler material interface.

Materials for use in the "like material" embodiments include:

- a polymeric material(s) with different refractive index, for example:

PMMA (polymethylmethacrylate)

- polymer plus dopant, for example:

doped PMMA (polymethylmethacrylate)

- inorganic, for example:

dielectric material,

soft glasses, such as fluoride glass and chalcoginide glasses.

- metallic, for example:

large polymer guiding rods with metallic material in the channels will block certain optical transmissions but guide RF and terahertz frequencies

- composite, for example:

two different polymers with different refractive index arranged as the channel material

combinations of the above

Further embodiments of the present invention will now be described with reference to Figures 3-7 where the filler material has a higher refractive index than the body material.

Figure 3 shows a cross sectional view of a core-region 302 of an optical fibre embodying the present invention. The core-region 302 comprises a main body material 306 having a refractive index n_0. A plurality of filled channels e.g. 304 are provided in the core-region 304, filled with a material having a refractive index n_1. The core-region 302 comprises a filled central channel 307, filled also with the material having refractive n_1. In this embodiment, the refractive index of the main body material 306 is lower than the refractive index of the filler material in the filled channels e.g. 304, i.e. $n_1 > n_0$.

Figure 4 shows the graded refractive index profile 400 of the core-region 302 shown in Figure 3. Also shown in Figure 4 is the theoretical graded index profile 402, which the core-

region 302 (Figure 3) was designed to approximate. The curve 402 shows the average circularly symmetric index profile of the actual fibre. As mentioned previously, the term "graded refractive index profile" is intended to include a profile such as that shown in 400 in Figure 4, which may sometimes be referred to as a multi-step refractive index profile.

Figure 5 shows a schematic cross sectional view of an optical fibre 500 embodying the present invention. The fibre 500 comprises a core-region 502, which in turn comprises hexagonal arrays of filled channels eg. 504, filled with a material having a refractive index n_f. The optical fibre 500 is formed from a main body material 506, and in the example embodiment, the refractive index of the main body material 506, n_b, is lower than the refractive index of the filler material, n_f, ie $n_f > n_b$.

Figure 6 shows the graded refractive index profile 600 of the core-region 502 shown in Figure 5. Also shown in Figure 6 is the theoretical graded index profile 602, which the core-region 502 (Figure 5) was designed to approximate. The curve 600 shows the average circularly symmetric index profile of the fibre 500 (Figure 5). Again, the term "graded refractive index profile" is intended to include a profile such as curve 600 in Figure 6, which may sometimes be referred to as a multi-step refractive index profile.

Table I summarises the design parameters for the fibre 500 shown in Figure 5, in an example embodiment.

Operating wavelength	633 nm
Channel size	3 μm diameter
Main body (PMMA) refractive index	1.49
Filler material refractive index	1.51
Minimum wall thickness	0.5 μm
Core-region size	100 μm diameter
Number of holes	331

Table I

Table II summarise the bandwidth properties of different lengths of the optical fibre 500 shown in Figure 5, in the example embodiment of Table I.

Length (m)	No mode mixing (MHz)	With Mode mixing approximation (MHz)
1	24195	24195
10	2420	7651
50	484	3422
100	242	2420
500	48	1082
1000	24	765

Table II

Figure 7 shows a schematic cross sectional view of another optical fibre 700 embodying the present invention. The fibre 700 comprises a core-region 702, which in turn comprises a hexagonal array of filled channels eg. 704, filled with a material having a refractive index n_f. The optical fibre 700 is formed from a main body material 706, and in the example embodiment, the refractive index of the main body material 706, n_b, is lower than the refractive index of the filled material, n_f.

Insert 708 shows the graded refractive index profile 710 of the core-region 702. Also shown in insert 708 is the theoretical graded index profile 712, which the core-region 702 was designed to approximate. The curve 710 shows the average circularly symmetric index profile of the fibre 700. Again, the term "graded refractive index profile" is intended to include a profile such as curve 710, which may sometimes be referred to as a multi-step refractive index profile.

Table III summarises the design parameters for the fibre 700 shown in Figure 7, in an example embodiment.

Operating wavelength	633 nm
Channel size	3 μm diameter

Main body (PMMA) refractive index	1.49
Filler material refractive index	1.51
Minimum wall thickness	0.5 μm
Core-region size	50 μm diameter
Number of holes	91

Table III

Table IV summarise the bandwidth properties of different lengths of the optical fibre 700 shown in Figure 7, in the example embodiment of Table III.

Length (m)	No mode mixing (MHz)	With Mode mixing approximation (MHz)
1	24136	24136
10	2414	7632
50	483	3413
100	241	2414
500	48	1079
1000	24	763

Table IV

The use of hexagonal-type structures such as the ones in the example embodiments described above with reference to Figures 5 to 8 can increase the quality of the obtainable graded index profile, ie. a closer match to a desired theoretical profile, eg. a parabolic profile, can be achieved. It is believed that one of the reasons for this improved quality attainable is the fact that hexagonal structures can provide high packing ratios, which can be utilised to increase the average index in the central region of the core-region. In a modification of such designs, channels may be selectively removed from the hexagonal areas in different embodiments of the present invention, to exercise further control over the achievable index profile.

In the following, some typical design features of optical fibres of the type described with reference to Figures 3 to 8, i.e. in which the refractive index of the filler material is higher than that of the body material, will be described.

- Light propagation in this type of fibre is through the filler material.

- The filler material could comprise one or more materials with indices and $n_1 \ldots n_x$, which are higher than n_0.

- A ratio of channel areas to main body area in cross-sectional ring areas around a central region of respective one or more core-regions of the fibre decreases as a function of distance from the central regions.

- The average effective index of the out layers in that type of fibre will be gradually lower than in the central region, i.e. lower than that of the filler material index. This results in the average effective index gradually decreasing with distance from the central region, thus creating a graded refractive index profile.

- The graded refractive index profile can be designed to manage or minimise modal dispersion.- The size of the core-region can be varied to above 0.5mm in diameter depending on design features such as variations on number of rings of channels, channel and main body ratio, the use of different channel arrangements, channel density and/or cross-sectional size and/or variations with radius, and/or other parameters.

- With currently available materials, polymer fibres of this type are expected to have a transmission window from 510nm to 1310nm. However, depending on the availability of future materials, this transmission window may well be expanded.

- By using higher refractive index material as the filler material, in optical fibres of this type the core-region supports selected modes, which reduces the number of modes significantly compared with designs of the type described above with reference to Figures 1 and 2. This can provide the following advantages:

- Due to the limited number of selected modes the modal dispersion between high order modes and the fundamental mode is reduced.

- No leaking modes exist, at least theoretically, in fibres of this type.

It is noted that in different embodiments of this type, the distribution, size, and/or shape of the channels can vary according to design requirements, as can the main body/filler material combination. Some of the design constraints are:

- physical limit of wall thickness between channels
- channel diameter

Fibres of this type may again be manufactured by a variety of different techniques, including for example hole drilling on a body polymer rod plus filling the filler materials into the holes to form a preform for subsequent drawing of the fibre. Another example is utilising casting and extrusion techniques, either for preform fabrication or direct formation of the optical fibre.

It is noted that in fibres of this type, the cladding material does not have to be provided as an additional component in the preform or fibre fabrication process. Rather, the main body of the polymer rod or cast provides the "envelope" of the cladding/core-region structure, into which the micro-structured core-region is manufactured, i.e. the guiding material is inserted/provided. At the same time, a further protective sleeve material may be provided, if required.

It is further noted that a hexagonal-type structures design may also be implemented with a filler material having a lower refractive index then the body material, in different embodiments. For such embodiments, design features similar to the ones described with reference to the embodiment shown in Figure 2 would be applicable.

In the following, a brief description of different manufacturing techniques for manufacture of polymer based microstructured signal guiding elements embodying the present invention is given.

By extrusion, injection moulding or similar thermomechanical techniques, an infinite number of arrangements of the core-region and cladding region (if desired) in the preform and consequently in the microstructured fibre can be produced. If the channels are air holes, for example, they may be provided by simply absence of optical fibre material, or alternatively using a blank which can later be removed from the resultant fibre.

The extrusion and injection moulding of plastics being in monomeric or polymeric form is a mature art and there are a wide variety of thermomechanical techniques such as extrusion dies and injection moulding apparatus which a person skilled in the art may use to prepare the above mentioned preforms and fibres.

For instance, in extrusion moulding, a die may be configured to provide a preform of optically suitable material with a series of channels there through. Either rigid or fluid lumens can be positioned within the die to produce the aforementioned channels. In a particularly preferred embodiment, such lumens are variable to alter the position of channels and thereby change the resultant characteristics of the fibre. In addition, the size, shape and orientation of the channels eg air holes can also be altered. With conventional techniques, the channels must ordinarily be circular in shape.

If the channels within the fibre are not air holes but, for example, filled with another optically suitable material, as described in the embodiments described above with reference to Figures 1 to 8, the extrusion die may be configured to have several injection points for such filling material.

By co-extrusion or injection moulding heterogeneous microstructured fibres or preforms may be produced, ie layers or areas of different optical materials. For instance, extrusion of a single monomer may be followed by selective polymerisation of certain areas to alter the refractive index. Alternatively, mixtures of various monomers/polymers/oligomers with different refractive indices may be provided directly to the extrusion die or mould. Different refractive indices may be provided by different dopants in the monomer/polymer applied to the die. Very complex fibres can also be manufactured using this process even allowing for heterogeneity along the length of the fibre or preform. The channels can be created within the fibre by leaving voids, or by extruding/moulding dummy materials in the relevant position, eg using the 'wax method' whereby the formed wax elements or other material is removed from the preform after extrusion/moulding to thereby leave the desired air holes.

By means of extrusion, the fibre or the preform can be continuously produced. Figure 8 shows a schematic drawing of a suitable system 800. It comprises a series of extruders 822 to 824 that may include heated vessel sections (not shown), in which the polymers 802, 803, 804 are polymerised or the polymer material may be line fed to the extruders 822 to 824. A conveyer pump 806 is used for the extrusion of the "preform" 808 through the core extruder 810. The use

of various patterned dies (not shown) for each material extruder enables the preform to be built up with the desired microstructure. An (optional) cladding extruder 812 is utilised to extrude a cladding layer around the preform 808 in a coating and drawing unit 814. In the unit 814, the drawing, i.e. reducing of the preform diameter, is effected. A diameter control unit 816 is provided, through which the drawn fibre 818 passes prior to collection on the fibre drum 820.

Direct extrusion is possible in some cases where the signal guiding element is formed directly from the base material(s). The more typical process involves extrusion of the preform, although the preform could be optionally annealed, and then followed by drawing and optionally coating of the optical fibre.

In addition, if at any stage a different microstructured optical fibre is required, for example with different channel arrangements, the die for extrusion can be altered. This is particularly important for microstructured fibres using photonic band gap effect. As will be appreciated by persons skilled in the art, the positioning and shape of the channels is crucial to such photonic band gap microstructured fibres. The above discussed continuous production technique may be used to rapidly provide the various channel arrangements allowing easy and rapid testing of various microstructured fibre structures.

An alternative method of producing structured polymer preforms suitable for subsequent drawing to form a microstructured polymer fibre involves casting. The entire preform may be cast as a unitary body, or smaller elements of the preform may be cast and combined to produce a polymer preform.

An issue to be addressed in casting or moulding a microstructured structure in polymers is that polymers are generally more dense than their corresponding monomeric solutions. This means that in general, although not in every case, shrinkage of the order of 4-8% occurs during polymerisation. This has the result of shrinking the resulting polymer form within the mould. This poses a particular difficulty when moulding around a rod, as the rod will tend to become trapped in the polymer. There are, however, a number of possible solutions to this problem, including:

(i) Mismatching the thermal expansion coefficients of the mould and the polymer so that heating or cooling causes the effective shrinkage of the mould relative to the polymer.

(ii) Using sacrificial moulds. For example, the moulds may dissolve or melt.

(iii) Using sacrificial coatings.

(iv) Using relatively "soft" moulds or coatings.

(v) Using "inflatable" moulds.

(vi) Coating or forming the mould surfaces with a material such as Teflon so as to reduce adhesion.

(vii) Heating the mould so that there is localised softening or melting of the polymer thereby allowing the rod to be removed.

(viii) Designing the cast structure in such a way that the holes are effectively interstitial holes, so that the opportunity for rods to become trapped is removed.

(iv) Using lubricant(s).

(x) Using memory metals.

In one embodiment illustrated in Figure 9, the casting may use patterned end plates 904, 906 connected by predetermined structures e.g. 902. These structures e.g. 902 may be polymer strings, which then become the filler material or can be removed to leave air channels or be replaced with another filler material. The casting process includes curing the polymer body material (not shown) in a preform receptacle (not shown) surrounding the predetermined structures e.g. 902 and abutting the end plates 904, 906.

It will be appreciated by the person skilled in the art that numerous modifications and/or variations may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

For example, it will be appreciated that the present invention in its broadest form is not limited to any particular disposition, dimensions or shapes of the channels, which may be dictated by the desired signal guiding properties of the signal guiding element.

Claims

1. A process of fabricating a polymer based microstructured signal guiding element having at least one core-region, the process comprising the steps of:

- forming a preform body from a polymer based body material;

- forming a plurality of channels in the preform body filled with a filler material having a different refractive index than the polymer based body material; and

- forming the signal guiding element from the preform body by a formation process,

wherein the filler material is chosen such that processing characteristics of the body material and the filler material relevant to the formation process of the signal guiding element are substantially similar, whereby the formation process is applied to the preform body incorporating the filled channels.

2. A process as claimed in claim 1, wherein the channels are disposed in the preform body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining the at least one core-region of the signal guiding element.

3. A process as claimed in claims 1 or 2, wherein the signal guiding element is arranged, in use, to transmit data in regions of the electro-magnetic spectrum within the optical regime or outside the optical regime, for example electromagnetic signals in the RF and/or terahertz range.

4. A process as claimed in any one of the preceding claims, wherein the channels extend substantially contiguously along the length of the signal guiding element.

5. A process as claimed in any one of the preceding claims, wherein the filler material comprises one or more of a group comprising a polymer, a polymer plus dopant, an inorganic material, a metal, and a composite material.

6. A process as claimed in any one of the preceding claims, wherein a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

7. A process as claimed in any one of the preceding claims, wherein the refractive index of the filler material is higher than that of the body material.

8. A process as claimed in claim 7, wherein light propagation in the core-region is, in use, through the filler material.

9. A process as claimed in any one of claims 6 to 8, wherein the central regions of the one or more core-regions are in the form of central channels filled with the filler material.

10. A process as claimed in any one of claims 1 to 5, wherein the refractive index of the filler material is lower than that of the body material.

11. A process as claimed in any one of the preceding claims, wherein the signal guiding element is arranged as a single-mode or a multi-mode signal guiding element.

12. A process as claimed in any one of the preceding claims, wherein the channels are disposed in the preform body such that the formed signal guiding element exhibits a desired modal dispersion and transmits data in a dispersion managed format.

13. A process as claimed in any one of the preceding claims, wherein the substantially similar processing characteristics of the body material and the filler material comprise one or more of a group comprising viscosity, coefficient of thermal expansion (CTE) and surface energy.

14. A process as claimed in any one of the preceding claims, wherein the step of forming the preform body from the body material and/or the step of forming the plurality of filled channels in the preform body comprises utilising casting techniques.

15. A process as claimed in any one of the preceding claims, wherein the step of forming the preform body from the body material comprises providing a solid or fluid rod of the body material manufactured utilising drawing and/or extrusion techniques.

16. A process as claimed in any one of the preceding claims, wherein the process is implemented utilising an extrusion system, wherein the forming of the preform body, the forming of the plurality of filled channels, and the forming of the signal guiding element steps occur substantially simultaneously during the formation process along an extrusion path of the extrusion system.

17. A process of fabricating a polymer based microstructured signal guiding element, the process comprising the steps of:

- forming a main body of the signal guiding element from a polymer based material; and

- forming a plurality of channels in the main body;

wherein the channels are disposed in the main body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining at least one core-region of the signal guiding element.

18. A process as claimed in claim 17, wherein a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

19. A signal guiding element as claimed in claim 17, wherein the channels are hollow or filled with a filler.

20. A polymer based microstructured signal guiding element having at least one core-region, the signal guiding element comprising:

- a main body made from a polymer based body material; and

- a plurality of channels in the main body filled with a filler material having a different refractive index than the polymer based body material;

wherein the filler material is chosen such that processing characteristics of the body material and the filler material relevant to a formation process of the signal guiding element are substantially similar, whereby the body material and the filler material have been subjected to said same formation process.

21. A signal guiding element as claimed in claim 20, wherein the channels are disposed in the preform body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining the at least one core-region of the signal guiding element.

22. A signal guiding element as claimed in claims 20 or 21, wherein the signal guiding element is arranged, in use, to transmit data in regions of the electro-magnetic spectrum within the optical regime or outside the optical regime.

23. A signal guiding element as claimed in any one of claims 20 to 22, wherein the channels extend substantially contiguously along the length of the signal guiding element.

24. A signal guiding element as claimed in any one of claims 20 to 23, wherein the filler material comprises one or more of a group comprising a polymer, a polymer plus dopant, an inorganic material, a metal, and a composite material.

25. A signal guiding element as claimed in any one of claims 20 to 24, wherein a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

26. A signal guiding element as claimed in any one of claims 20 to 25, wherein the refractive index of the filler material is higher than that of the body material

27. A signal guiding element as claimed in claim 26, wherein light propagation in the core-region is, in use, through the filler material.

28. A signal guiding element as claimed in any one of claims 25 to 27, wherein the central regions of the one or more core-regions are in the form of central channels filled with the filler material.

29. A signal guiding element as claimed in any one of claims 20 to 24, wherein the refractive index of the filler material is lower than that of the body material.

30. A signal guiding element as claimed in any one of claims 20 to 29, wherein the signal guiding element is arranged as a single-mode or multi-mode signal guiding element.

31. A signal guiding element as claimed in any one of claims 20 to 30, wherein the channels are disposed in the preform body such that the formed signal guiding element exhibits a desired modal dispersion.

32. A signal guiding element as claimed in any one of claims 20 to 31, wherein the substantially similar processing characteristics of the body material and the filler material comprise one or more of a group comprising viscosity, coefficient of thermal expansion (CTE) and surface energy.

33. A polymer based microstructured signal guiding element comprising:

- a main body made from a polymer based material; and

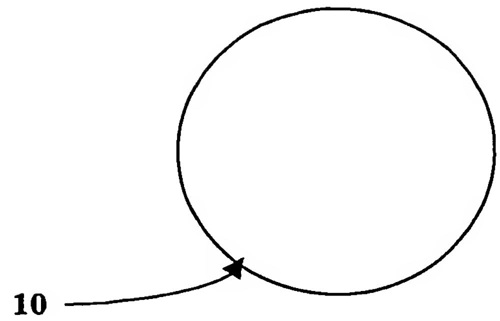
- a plurality of channels in the main body;

wherein the channels are disposed in the main body such that the formed signal guiding element exhibits a substantially graded refractive index profile defining at least one core-region of the signal guiding element.

34. A signal guiding element as claimed in claim 33, wherein a ratio of channel areas to main body area in cross-sectional ring areas around a central region of the respective at least one core-regions decreases as a function of distance from said central regions.

35. A signal guiding element as claimed in claim 33, wherein the channels are hollow or filled with a filler material.

A)



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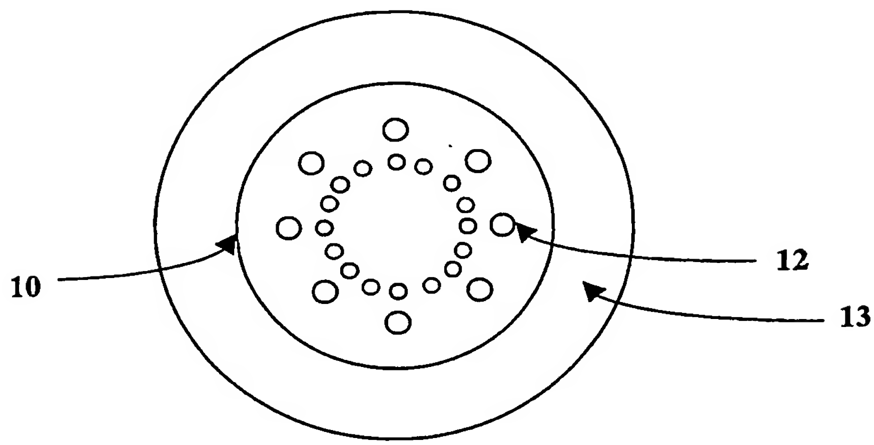

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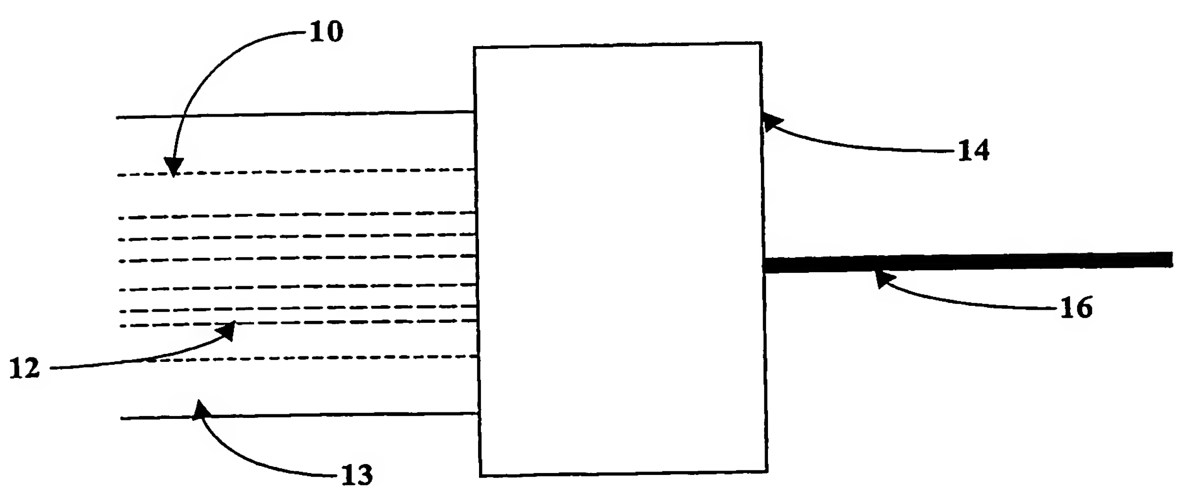

Figure 1

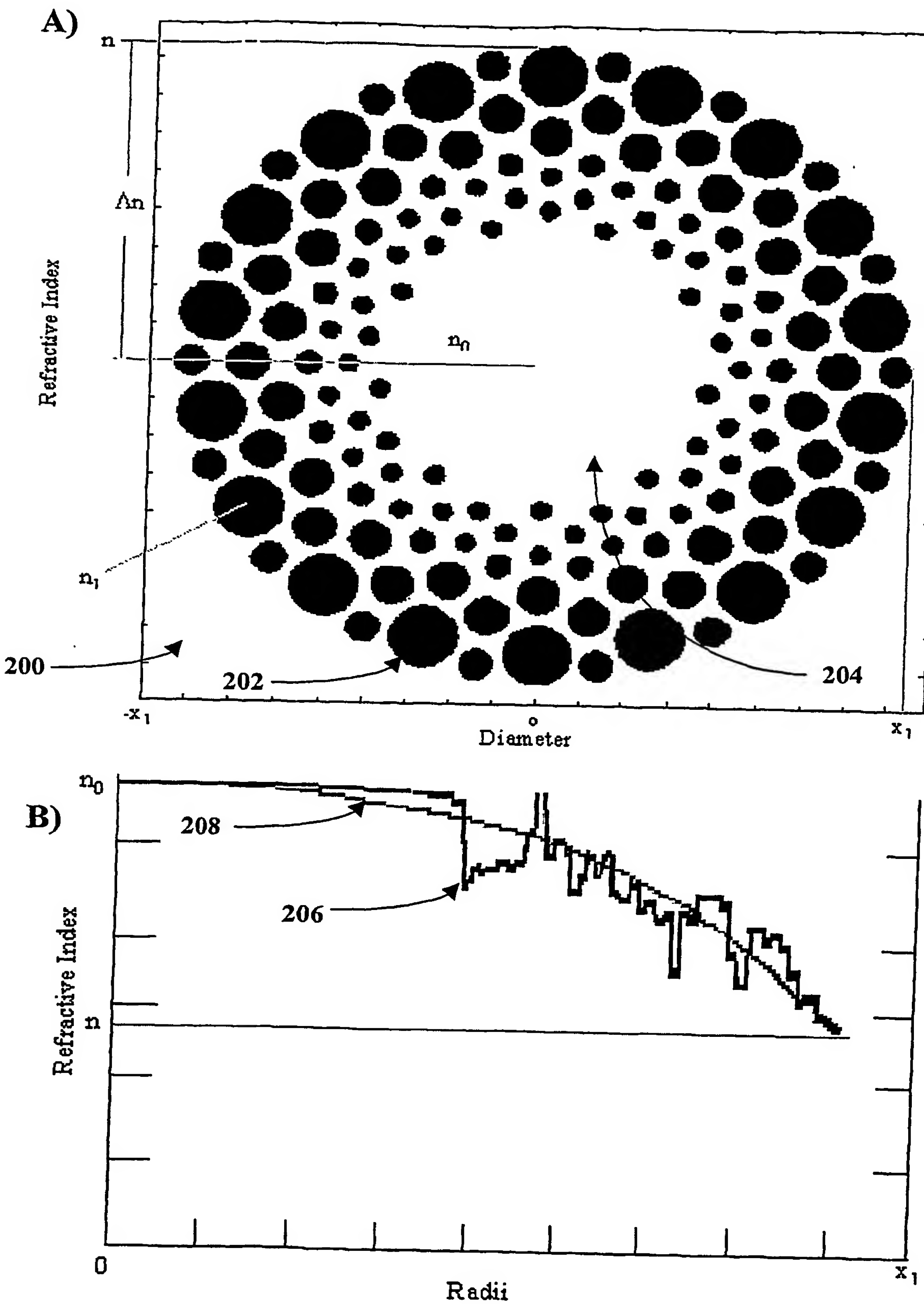
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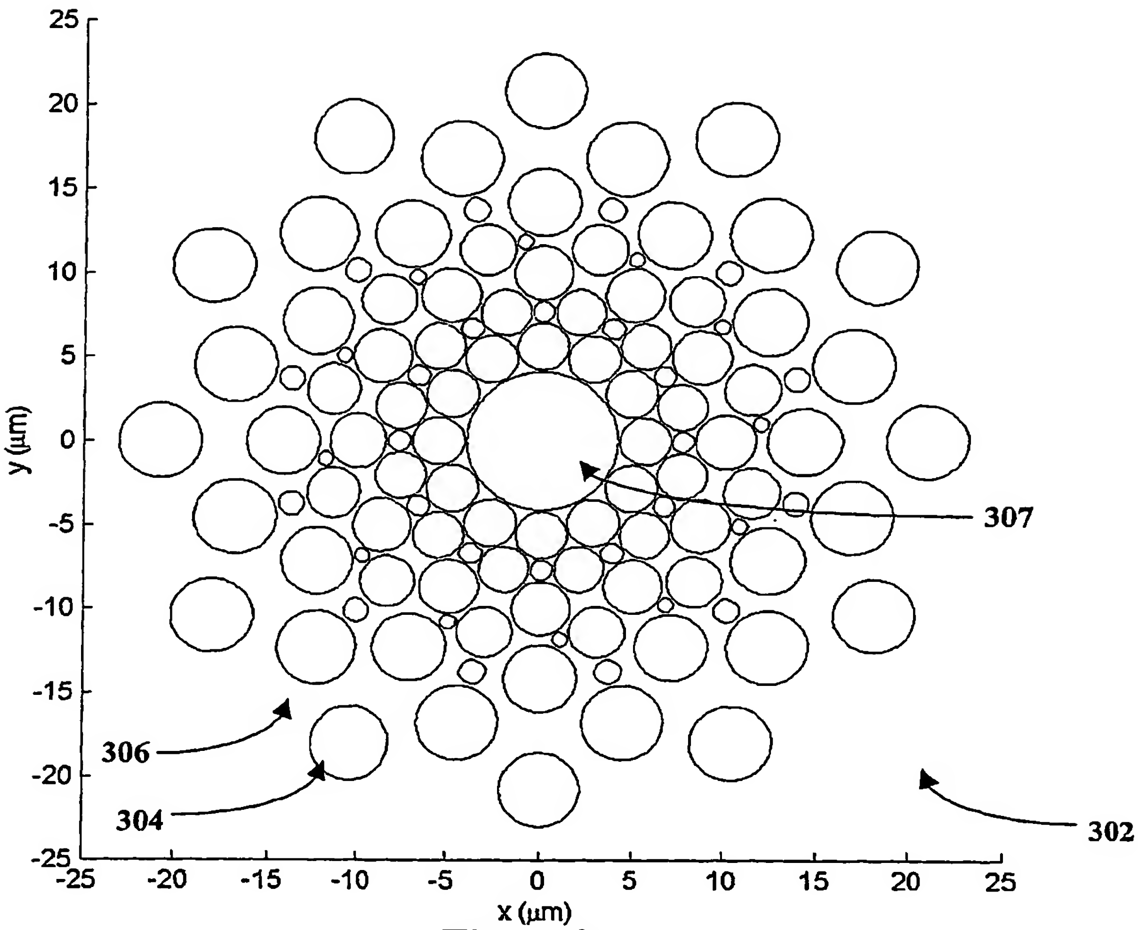
Figure 2



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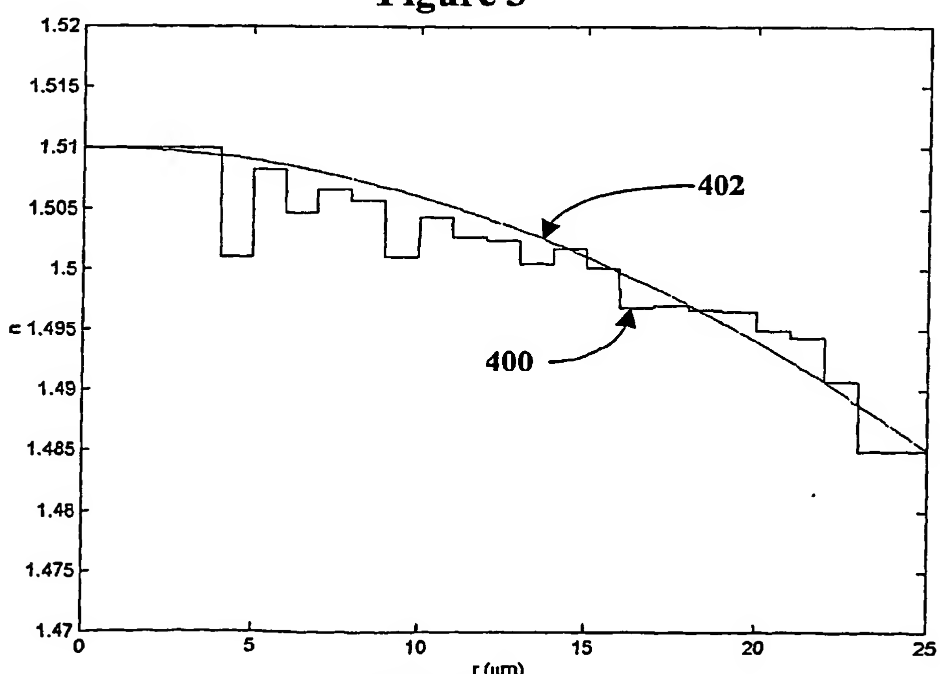

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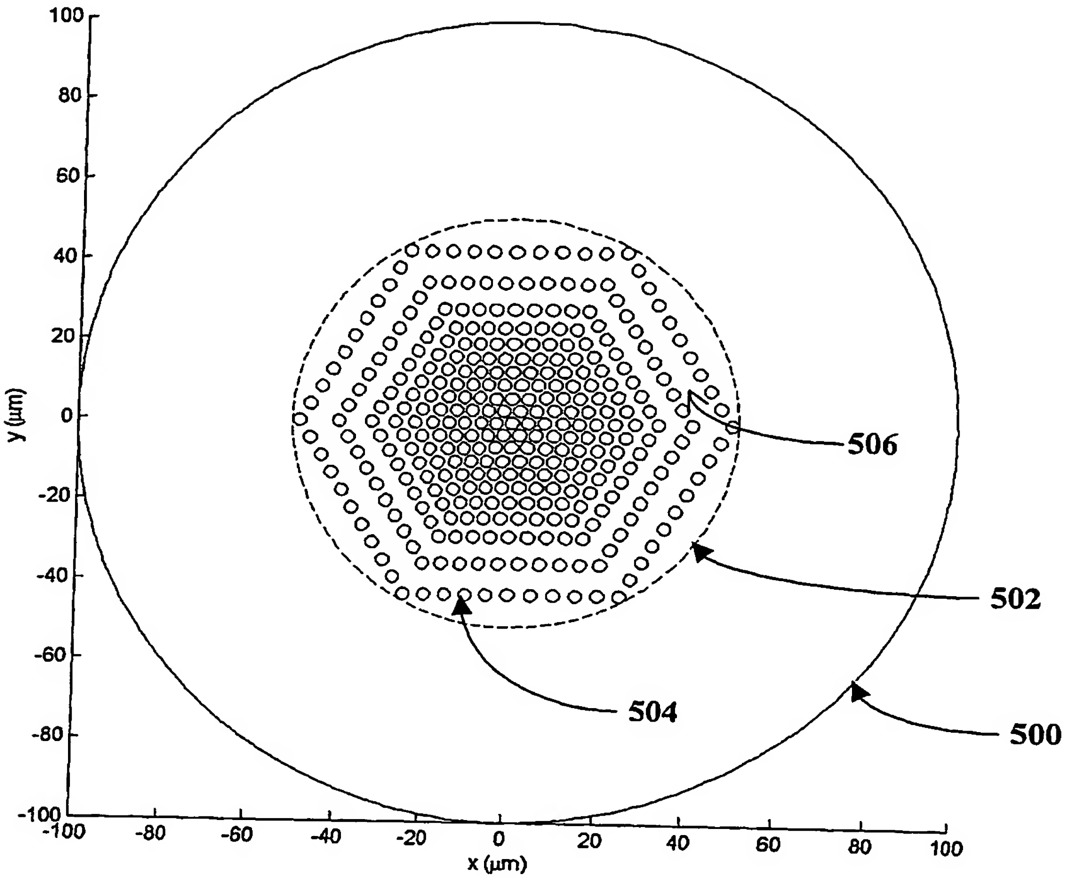
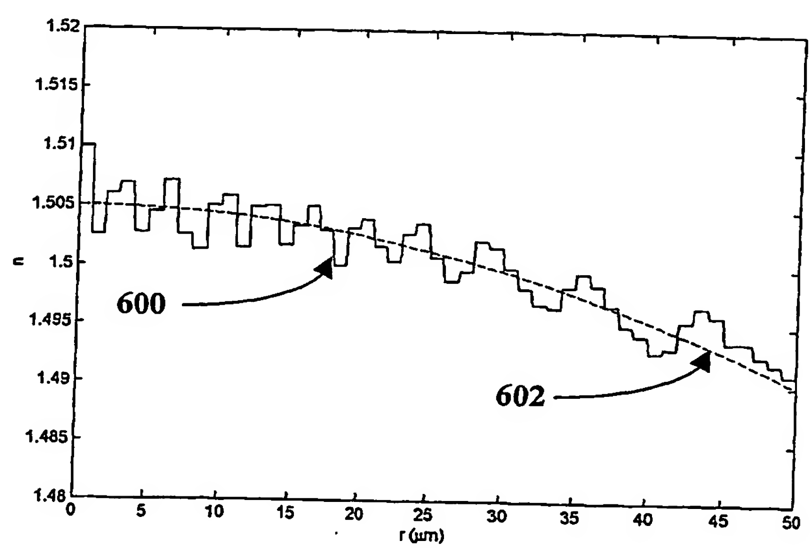


Figure 5



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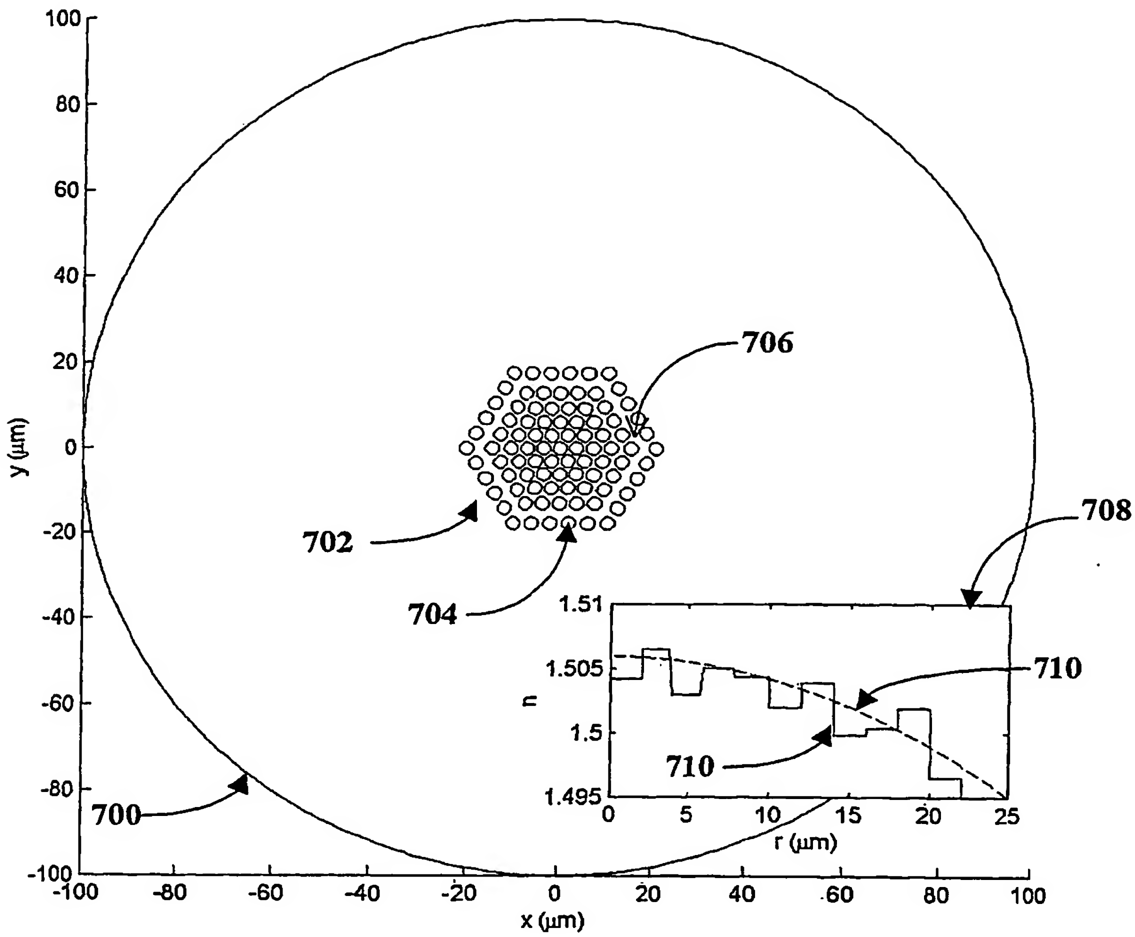
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Figure 7

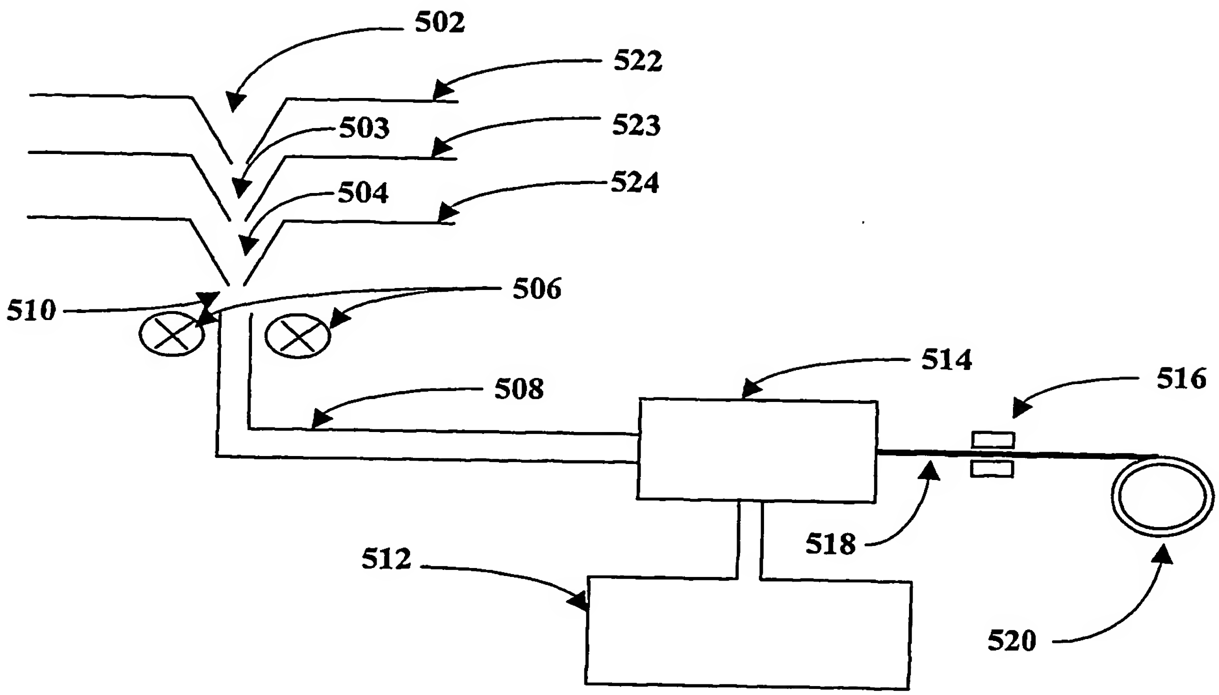

Figure 8

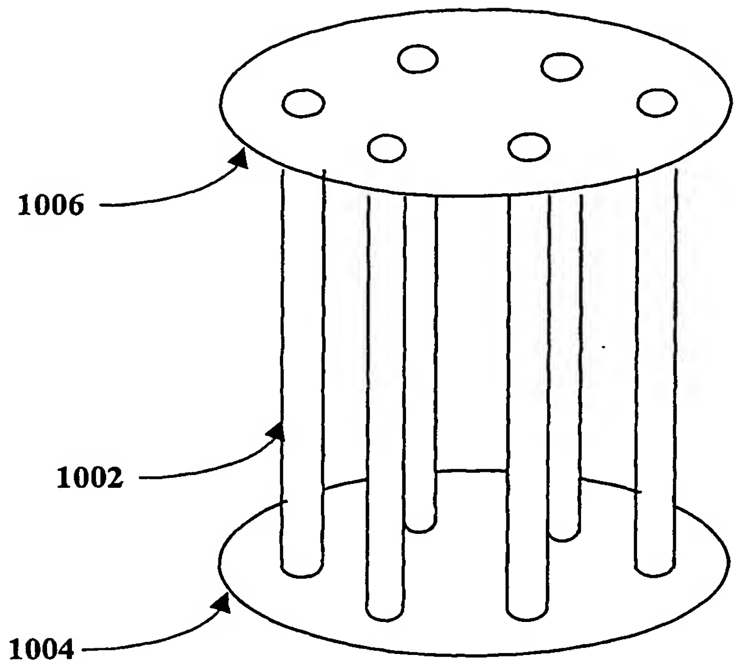

Figure 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2003/001564

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. 7: G02B 6/16, 6/18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DWPI, JAPIO: keywords [(microstructure?, micro-structure?)(2w)(+guid+, fib+)]; [(holey, photonic crystal, photonic band+)(2w)(+guid+, fib+)]

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2002/016984 A (THE UNIVERSITY OF SYDNEY) 28 February 2002 (& WO 02/16984 A) Page 6 lines 25-30, page 8 lines 19-30, figure 4	1-13, 17-35 14-16
P, X P, Y	WO 2002/095460 A (REDFERN POLYMER OPTICS PTY LTD) 28 November 2002 (& WO 02/095460 A) Page 4 lines 18-25, page 7 lines 18-32, page 11 lines 20-23, figure 3	1-35 14-16
P, X	WO 2002/101422 A (SAMSUNG ELECTRONICS CO LTD) 19 December 2002 (& WO 02/101422 A) Page 5 line 24 - page 8 line 7, figures 2-5	1, 3-5, 7-16, 20, 22-24, 26-32

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search 20 January 2004	Date of mailing of the international search report 27 JAN 2004
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer IRINA TALANINA Telephone No : (02) 6283 2203

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2003/001564

C (Continuation). **DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6188824 B (TESHIMA) 13 February 2001 Col. 6 lines 23-56, figures 1-4	1, 3-5, 7-9, 13, 16, 20, 22-24, 26-28, 32
P, X	WO 2003/009028 A (THE UNIVERSITY OF SYDNEY *et al.*) 30 January 2003 (& WO 03/009028 A) Page 7 lines 23-33, page 9 lines 21-31, figures 2, 3	17-19, 33-35

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2003/001564

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
WO	0216984	AU	72230/01	CA	2420075	EP	1320774
WO	02095460						
WO	02101422	KR	2003026336				
US	6188824	WO	9835247				
WO	03009028						

END OF ANNEX